# Experimental Investigation On Replacement of Fine and Coarse Aggregate by Steel Slag in Concrete

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***Abstract***: *Throughout the entirety of the construction project, engineers endeavour to employ materials that can efficiently decrease time and costs, as well as alleviate the common challenges faced at different construction sites. The integration of steel slag aggregate in concrete construction has proven to be crucial in tackling a variety of issues while also fostering early strength development in the structures. Steel slag is a by-product that emerges during the production of primary steel, and a typical method of managing it involves storing it in designated slag disposal sites. The substantial generation of steel slags over time and the continuous utilization of these sites have resulted in the extensive utilization of land resources and have raised notable environmental concerns. Its physical and chemical characteristics render it suitable for various purposes. The study conducted entailed experimenting with different ratios for slag-aggregate substitution in concrete mixes aimed at achieving a strength of 30 MPa. The results of the research clearly demonstrate that incorporating steel slag enhances the levels of concrete strength without compromising the material's workability. This study primarily focused on the physical attributes and mechanical properties of steel slag aggregate concrete.*

***Keywords*****:** Steel slag, Workability, Physical Property Mechanical property.

## 1. INTRODUCTION

Concrete is a commonly utilized substance that holds great importance in the realm of nation-building due to its direct impact on infrastructure and the [1] economy. Comprised of coarse granular materials known as aggregates or filler, concrete functions as a composite material that is bound together by cement or other binding agents. Aggregates, typically sourced from natural rocks in the form of crushed [2] stones or gravels, play a vital role in the composition of concrete. Aggregate accounts for three quarters of the concrete volume, the quality and properties of aggregates[3] significantly influence the strength, durability, and serviceability of concrete. As such, the quest to find suitable alternatives to natural aggregates has proved to be a demanding task. Currently, there is a growing interest in utilizing waste [4]materials as alternative [5]aggregate substances, leading to extensive research on various materials such as coal ash, blast furnace slag, and steel slag as potential substitutes. This approach not only[6] address the shortage of aggregates in different construction sites but also mitigates environmental concerns associated with aggregate [7]mining and waste disposal. Steel slag, a by-product of iron and steel manufacturing processes, is generated in substantial quantities and holds potential as a viable alternative aggregate material. The steel slag produced during the conversion of iron to steel is deposited in beds and gradually cooled under normal atmospheric conditions. The utilization of slag in concrete not only contributes to the reduction of greenhouse gases but also[8] aids in the creation of an environmentally friendly material.

The integration of steel slag in construction can reduce reliance on natural rock resources, preserving limited reserves. Utilizing by-products, [9] including recycled waste materials and sand, has led to progress in effective use of slag. Steel slag in concrete mixes has effectively overcome [10] challenges in the sector, enhancing mechanical, physical, and chemical characteristics and improving overall quality. Reutilizing industrial waste slag contributes [11] to sustainability and resource efficiency. However, drawback may include expansion and adverse interactions with [12] concrete components. Research and development efforts are addressing these challenges to optimize steel slag performance for enhanced sustainability. Advancements in steel [13] slag utilization technology and best practices are expected to [14]drive innovation in the construction industry, promoting sustainable and environmentally friendly building practices.

## LITERATURE REVIEW

Zhichao Liua et al;2021, Haima Zengb, Fazhou Wang et al;2021 The study[15] introduces carbon table concrete (HPCC) as a variant of concrete that effectively utilizes steel slag. HPCC has a densely packed particle size distribution with steel slag accounting for 90% of the binder. It demonstrates high fluidity and manageability. After pre-drying treatment, HPCC achieves compressive strengths of 104.9 MPa and 173.7 MPa after 12 hours and 7 days of carbonation curing, respectively. This increased strength is attributed to the consolidation of the densely packed structure, evident from microstructure and pore characteristics. HPCC exhibits minimal moisture absorption similar to ultra-high-performance concrete (UHPC), indicating resistance to harmful external substances. Additionally, HPCC shows lower moisture absorption from carbonation-induced deformation compared to UHPC, leading to improved volume stability. This is due to the consumption of calcium oxide (CaO) and periclase during carbonation. Overall, HPCC has great potential for efficiently utilizing steel slag while maintaining efficacy.

Amr M. Ibrahim et al;2021, Ashraf R. Mohamed Mona Elsalamawy et al;2021 The [16]research project aimed to evaluate the impact of aggregate substitution on the mechanical, gamma-ray shielding, and thermal properties of high-density concrete. Different amounts of hematite and iron slag were used as substitutes for crushed limestone aggregate in concrete mixtures. The results showed that incorporating hematite and iron slag improved the shielding properties of concrete when exposed to point sources of radiation. Additionally, the inclusion of 30% hematite or iron slag significantly enhanced compressive strength, with concrete mixtures containing 30% slag exhibiting the highest specific intensity limit.

J. Baalamurugana et al;2021, V. Ganesh Kumara, et al;2021, S. Steel slag is increasingly being used as a substitute for normal aggregate in the construction of concrete. It not only reduces the negative environmental impact but also improves the performance [17]of cement in terms of radiation protection. However, there are limitations to using steel slag in concrete. This review aims to explore and analyse the development of a high-mass radiation protecting composite using induction furnace (IF) steel slag in concrete. Experimental [18]concrete samples with varying proportions of IF steel slag were created and analysed using X-ray diffraction (XRD) and electron microscopy (SEM). The results [19] show that substituting slag in concrete increases both the mass and compressive strength compared to traditional cement. Additionally, the radiation shielding properties of the concrete with slag are higher than those of regular cement.

Xueqin Chen et al;2020, Guotong Wang et al;2020 The utilization of Steel Slag Total (SSA) in pervious substantial holds critical potential as an answer [20]for Low Effect Improvement (Top) and feasible asphalt materials. A progression of tests utilizing AI technology were directed to investigate how SSA improves pervious cement when contrasted with limestone. The outcomes showed that the modulus and hardness of the interfacial change zone (ITZ) in SSA[21] pervious cement were 44% and 68% more prominent, separately. The thickness of the ITZ in SSA pervious cement was additionally found to be less when contrasted with limestone. Moreover, the SSA pervious cement showed a denser structure and a higher amount of hydration items. These discoveries propose that SSA brings the ITZ up in pervious cement through expanded strength, diminished width, and a denser design.

OsmanGencela et al;2021, OmerKaradag et al;2021. The use of steel slag in concrete and construction projects was examined and its impact on the environment was analysed. The physical and chemical properties of steel slag and its effect on cement properties were[22] studied, along with its applications in different industries. The literature on steel slag utilization in the concrete and construction industry was thoroughly reviewed. The findings and outcomes of these studies were evaluated, and the potential effects[23] of these by-products were discussed. The challenges related to storage and environmental impact were assessed globally, and ways to reintegrate them [24] into the industry were explored. The economic[25] and environmental benefits were also investigated, and various perspectives and recommendations were put forth.

# 3.MATERIALS

## 3.1. Cement

OPC 53 Grade Cement complies with the standards set by BIS Specification IS 12269-1987. Its durable nature is attributed to its specific particle size and robust crystalline composition. Cement, serving as an adhesive material in construction, consists of finely powdered varieties that solidify upon contact with water.

**Figure 1.** Cement

**Table 1**. Physical Properties of Cement

| Sl. No | Tests | Result | IS specification |
|---|---|---|---|
| 1. | Fineness | 5% | Not more than 10% (IS 12269 2013) |
| 2. | Consistency | 29% for 5.0mm penetration | Penetration 5-7mm frombottom (IS 4031 Part 3) |
| 3. | Initial setting time | 40minutes | Shall not be less than 30minutes (IS 4031 Part 4) |
| 4. | Final setting time | 350minutes | Shall not be less than 10hours (IS 4031 Part 4) |
| 5. | Specific gravity | 3.12 | 3.1 to 3.16 (IS 4031- Part 11) |

## 3.2.M -Sand

Manufactured sand (M- sand) serves as a superior alternative to river sand in construction due to its high quality. It is produced by crushing tough granite rocks to ensure consistent quality and particle size distribution. M sand provides various advantages including increased strength, enhanced shape, and reduced impurities, making it suitable for concrete manufacturing. Its uniform nature contributes to improved workability and durability of concrete structures. Moreover, M sand aids in mitigating environmental impacts from river sand extraction, thereby promoting sustainable construction practices. Owing to these benefits, M sand has become increasingly popular as a dependable and environmentally friendly substitute for conventional river sand in the construction sector.

**Figure 2.** M-Sand

**Table 2**. Physical Properties of M Sand

| Sl. No | Tests | Result | IS specification | Inference |
|---|---|---|---|---|
| 1. | Particle size distribution | Grading Zone -II | IS383 1970 | Confirm to IS specification |
| 2. | Specific gravity | 2.78 | 2.5-3 (IS 2720-Part III) C | Confirm to IS specification |

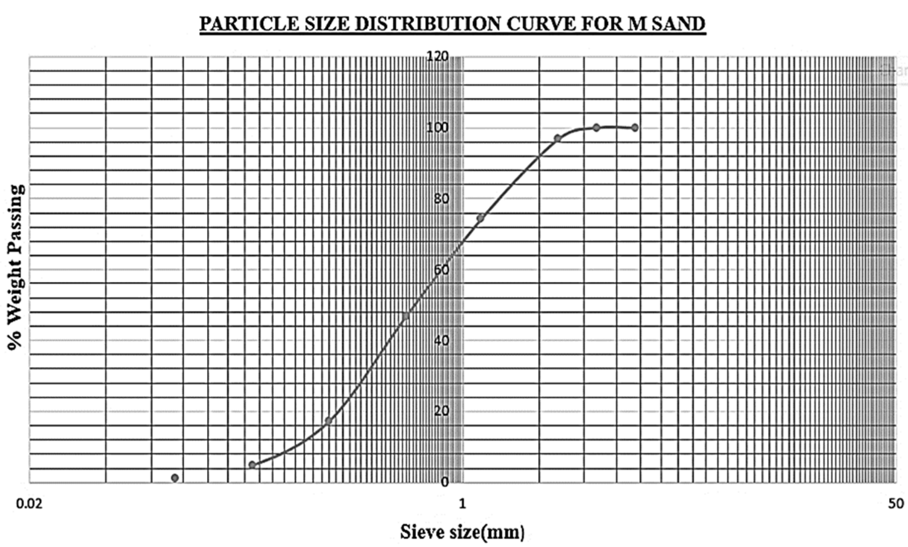


**Figure 3.** The Particle Size Distribution Curve of Fine Aggregate

## 3.3. Coarse Aggregate

Machine-crushed aggregates are comprised of stones of varying sizes, in contrast to hand-broken aggregates which are uniform in size. The study utilizes coarse aggregates ranging from larger than 4.75 mm to 63 mm, with a specific size of 20mm. To maintain quality, the presence of lignite, coal, soft fragments, and clay lumps in the aggregate should not surpass 5% of the total weight. These aggregates play a crucial role in enhancing the mechanical characteristics and longevity of concrete mixtures by providing volume and stability. Their shape, whether angular or rounded, facilitates interlocking and enhances resistance to compressive and shear forces. Proper classification guarantees an ideal distribution, packing density, and diminishes empty spaces, thereby boosting strength and workability.

**Figure 4.** Coarse Aggregate

**Table 3**. Physical Properties of Coarse Aggregate

| Sl. No | Tests | Result | IS specification |
|---|---|---|---|
| 1. | Specific Gravity | 2.5 | 2.5-3.0 As per IS 2386-3 |
| 2 | Bulk density | 1.42g/cc | 1.20g/cc -1.75g/cc |
| 3 | Void ratio | 3.25% | Between 1%-15% |
| 4 | Porosity | 42.85% | Between 30%-45% |
| 5 | Water absorption | 0.43% | 0.1 -2.0 % |

## 3.4. Steel Slag Aggregate

Steel slag is a secondary product of the steel production process, resulting from the reaction of impurities found in primary materials such as iron ore, coal, and limestone as they are eliminated from the liquid steel. These impurities, including silicon, phosphorus, sulphur, and excessive carbon, form a liquid slag with lime that rises to the surface of the steel, solidifying after cooling. There are two main categories of steel slag: basic oxygen furnace (BOF) slag produced during basic oxygen steelmaking, and electric arc furnace (EAF) slag produced during electric arc furnace steelmaking.

**Figure 5**. Steel Slag Aggregate

**Table 4**. Physical Properties of Steel Slag Aggregate

| Sl. No | Tests | Obtained value |
|---|---|---|
| 1. | Specific Gravity | 2.5 |
| 2 | Bulk density | 1.42g/cc |
| 3 | Void ratio | 3.25% |
| 4 | Porosity | 42.85% |
| 5 | Water absorption | 0.43% |
| 6 | Particle size distribution of fine steel slag | Grading Zone -II |
| 7 | Specific gravity of fine steel slag | 2.78 |

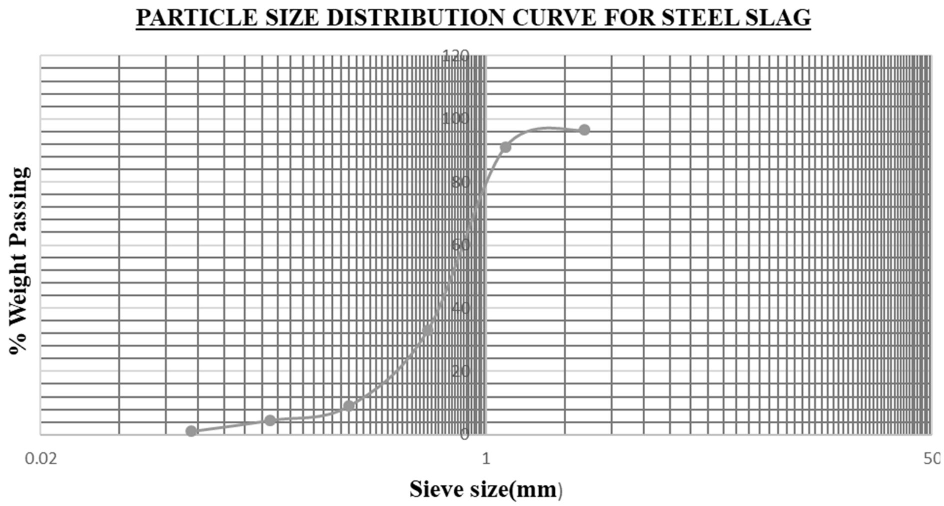


**Figure 6**. The Particle Size Distribution Curve of Fine Steel Slag Aggregate

## 4.MIX DESIGN

The concrete mixture used in production was formulated following the mix design method outlined in IS 10262-2019, with a strength grade denoted as M30. This standard provides cost-efficient material combinations for concrete, detailing specifications for different types. The proportions of the mix were 1:1.43:2.25 for cement, fine aggregates, and coarse aggregates. The process involved manual blending, starting with the addition of aggregates, followed by cement and slag. Water was incorporated into the final mix. Various amounts of steel slag were utilized to substitute different percentages (ranging from 10% to 80%) of the fine (SSFA) and coarse aggregates (SSCA).

Table 5 Mix Proportion of Materials

| Mix | Cement (Kg) | Fine Aggregate (Kg) | Coarse Aggregate (Kg) | Steel slag (Kg) | water (Kg) |
|---|---|---|---|---|---|
| Control mix | 6.588 | 9.435 | 14.866 | 0 | 2.754 |

## 5.RESULTS AND DISCUSSION

### 5.1Slump Test

The slump cone test, also known as the concrete slump test, is used to determine the workability or consistency of concrete. It is conducted on successive batches of concrete to ensure consistent quality throughout the construction process. The test measures the water-to-cement ratio and is influenced by various factors such as material qualities, blending procedures, measurements, and admixtures. These variables also affect the concrete's substantial rut value.

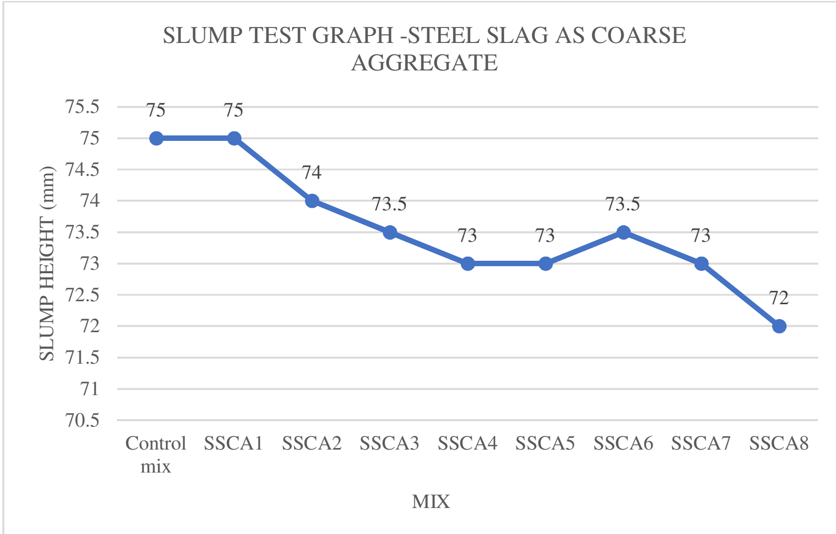


**Figure 7.** Slump Test Graph -Steel Slag as Coarse Aggregate

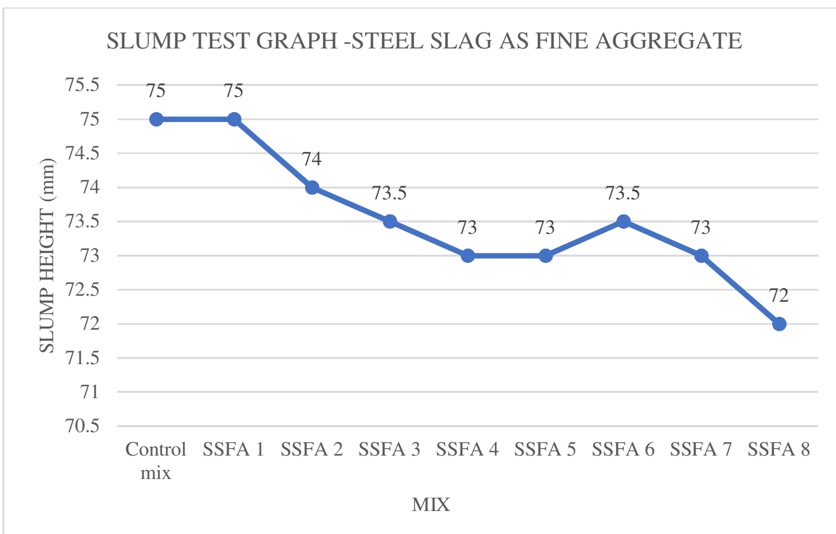


**Figure 8.** Slump Test Graph -Steel Slag as Coarse Aggregate

## 5.2 Compressive Strength Test

The compressive strength test evaluates a material's ability to withstand compressive forces. It is important in construction and engineering to ensure structural integrity and safety by meeting durability requirements.


**Figure 9.** Compression Testing Machine

**Figure 10**. Crack on cubes

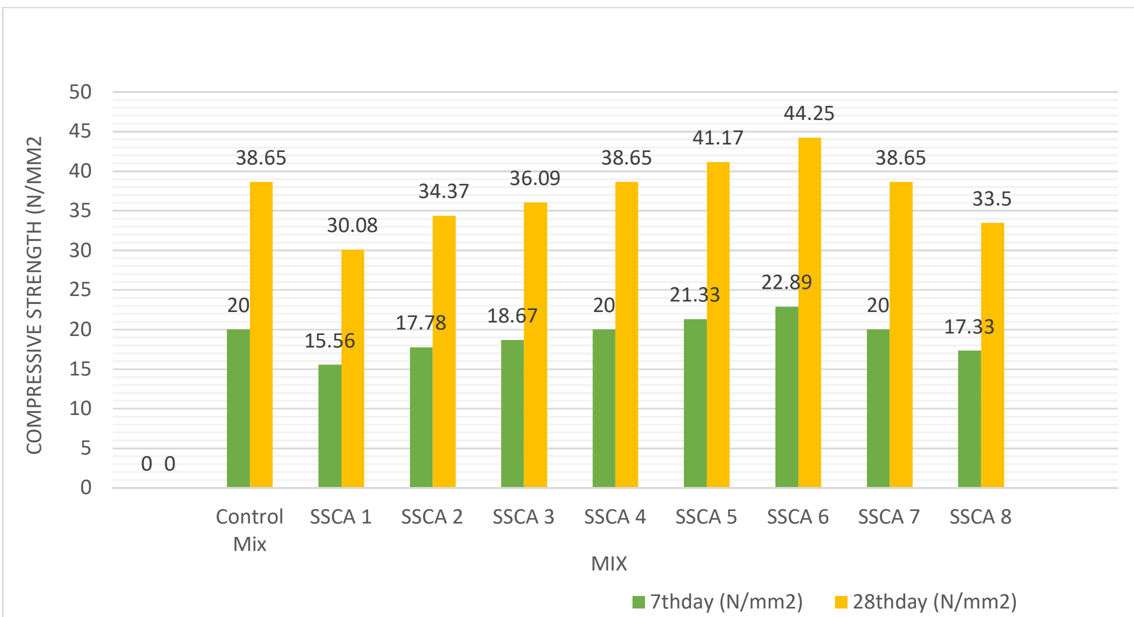


**Figure 11.** Compressive Strength Graph of Coarse Aggregate Replaced

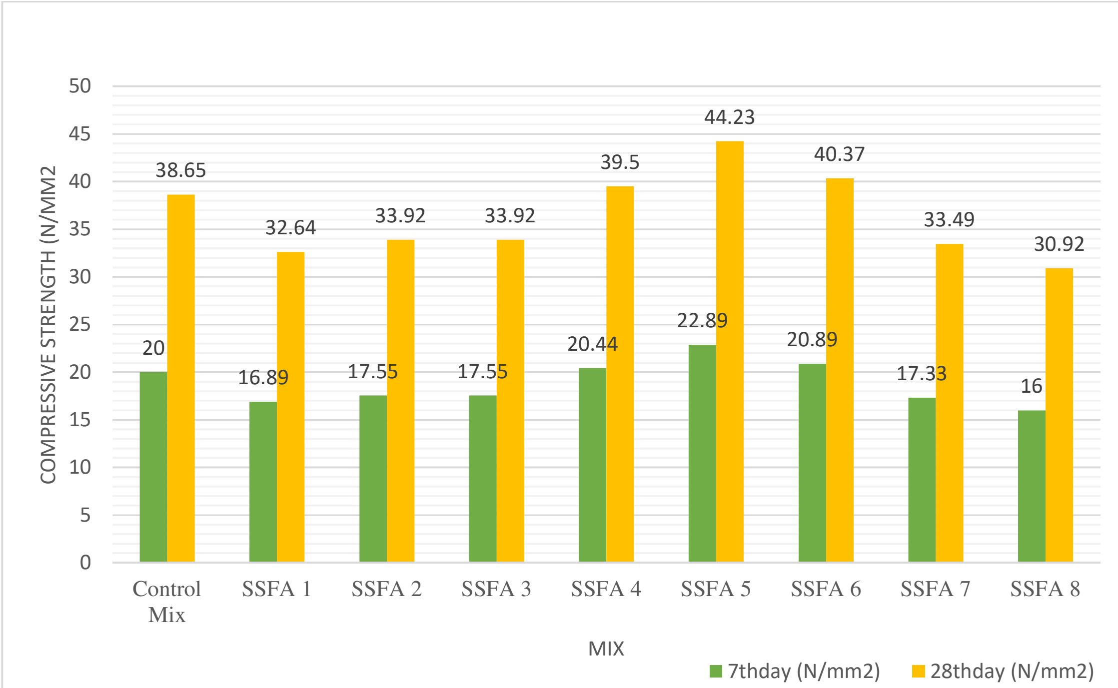


**Figure 12.** Compressive Strength Graph of Fine Aggregate Replaced

## 5.3 Split Tensile Strength Test

The tensile strength test measures a material's ability to resist breaking under tension. It involves pulling a sample until it fractures to determine its maximum stress tolerance. This parameter is crucial in engineering, manufacturing, and materials science. Tensile strength testing ensures the reliability of materials used in various applications. The formula for calculating tensile strength is $2P/(\pi DL)$, where P is the force required to split the cylinder, D is its diameter, and L is its length.

**Figure 13.** Compression Testing Machine


**Figure 14.** Crack on cylinder

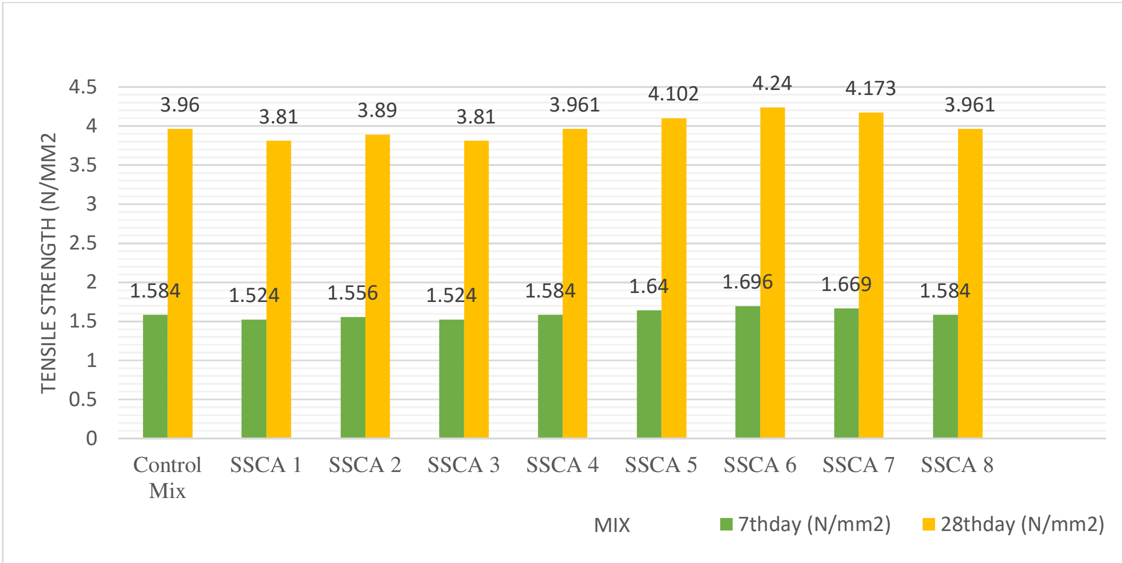


**Figure 15.** Tensile Strength Graph of Coarse Aggregate Replaced

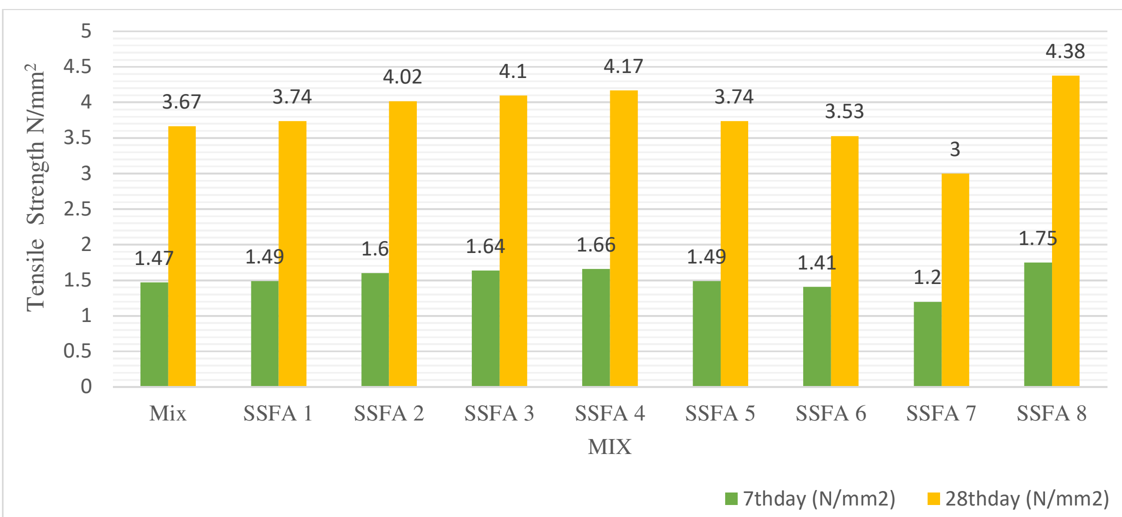


**Figure 16.** Tensile Strength Graph of Fine Aggregate Replaced

## 5.4 Flexural Strength Test

The flexural strength test evaluates a material's resistance to bending and measures the maximum load it can bear before fracturing. This test is essential for assessing structural integrity and suitability for applications in construction, aerospace, and manufacturing.

**Figure 17.** Flexural Strength Testing Machine

**Figure 18.** Crack On Beam

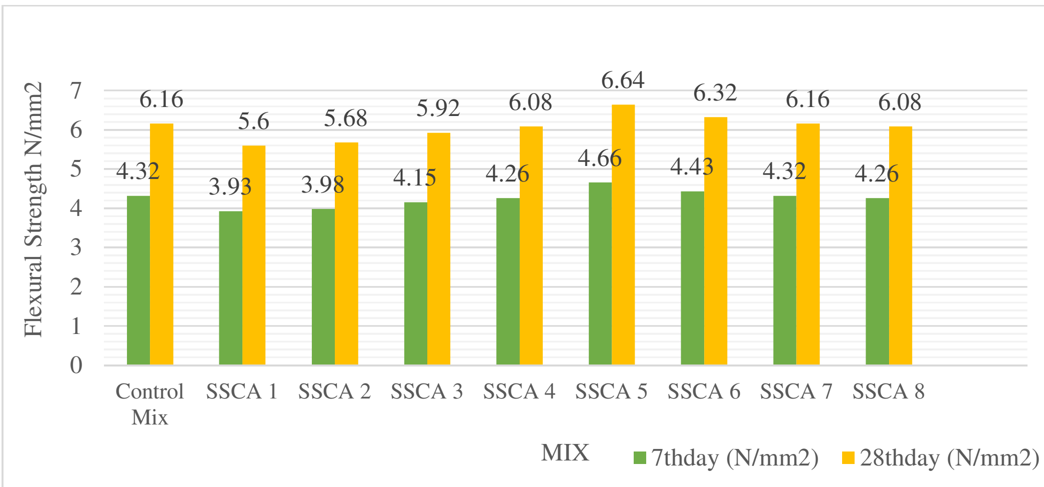


**Figure 19.** Flexural Strength Graph of Coarse Aggregate Replaced

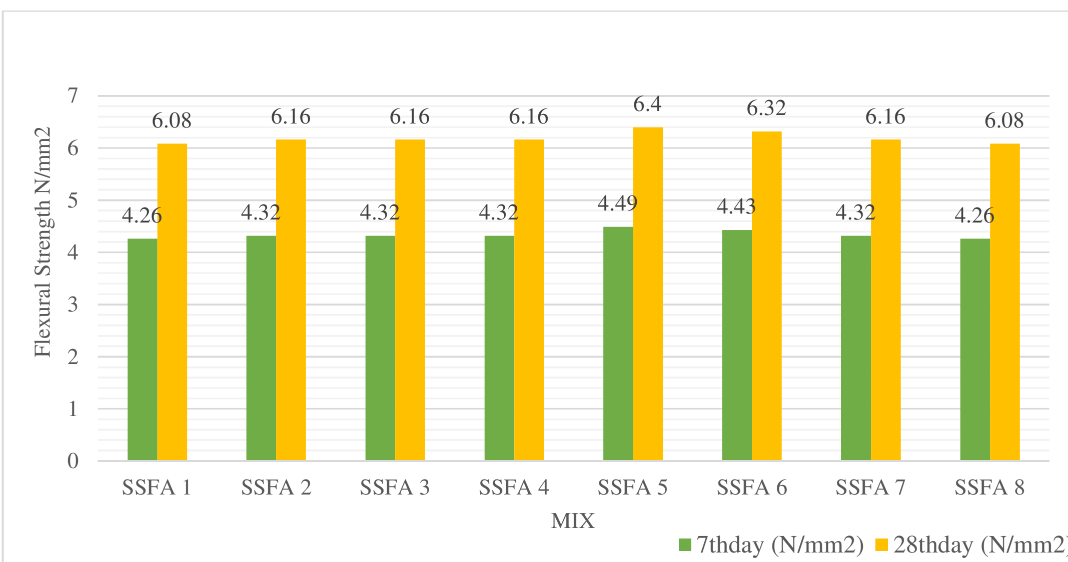


**Figure 20.** Flexural Strength Graph of Fine Aggregate Replaced

## CONCLUSION

- Both steel slag and natural aggregates (whether coarse or fine) can be processed to achieve specific particle size distributions. Controlling particle size is crucial for determining the workability, strength, and overall performance of concrete and other construction materials.
- The shape and texture of particles in both steel slag and natural aggregates can influence the workability and strength of concrete. Both materials can have angular or rounded particles, impacting the overall mix characteristics.
- The porosity of steel slag and natural aggregates (both coarse and fine) can be comparable. Porosity is relevant to the permeability of concrete and its resistance to moisture ingress.
- Steel slag typically has a higher water absorption capacity compared to natural aggregates. The porous nature of steel slag, resulting from its production process and mineral composition, can lead to increased water absorption
- The results showed that physical properties are similar to conventional aggregate so steel slag can be used in construction industry as aggregate in concrete as natural aggregate. Natural aggregates are becoming scarce and their production is difficult. So there arises a need for alternate material as coarse aggregate and fine aggregate.
- The results of the slump test showed that at 0% replacement level, the concrete mix gave a true slump value of 75mm. The slump decreases, as the percentage replacement level increases, from 0%to80%. It shows that Water absorbing property of steel slag in fine and coarse aggregate is higher than that of M sand and Coarse aggregate. From the graph it is observed that in concrete, percentage of steel slag increases, it decreases the workability.
- The inclusion of steel slag in concrete mixes has minimal impact on workability. The introduction of slag enhances the strength of concrete, resulting in improved compressive, tensile strength and flexural strength.
- Optimal benefits are achieved in fine aggregate replacement by replacing 50% of M-sand with steel slag. Optimum replacement percentages of steel slag are 60% coarse aggregate.

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